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MPROVIOT - Multi-Purpose IoT Rover Robot

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Abstract: Robots can be used in various fields due to their flexibility and diversity. This research focuses on designing and developing a multifunctional rover robot for research, exploration, and educational purposes. The main objective of the research is to design a Rover robot platform with remote control, IoT technology. Various scenarios have been created to test the robot's different capabilities, and its performance has been observed. The collected data have been analyzed using both qualitative and quantitative methods. The developed rover robot can be successfully controlled both through RC and IoT controls. Moreover, a web server has been developed for the IoT aspect of the robot, and both arm and head camera images of the robot are transmitted as IoT. The robot's modular design ensures suitability for various tasks and makes it suitable for educational purposes. The results of this study indicate the potential of multifunctional rover robots for various applications and their effectiveness as educational tools.

MPROVIOT – Çok Amaçlı IoT Rover Robot

Anahtar Kelimeler
Arduino,
Rover robot,
Nesne tespiti,
Sensör,
IoT

Öz: Robotlar esneklik ve çeşitlilikleriyle farklı alanlarda kullanılmaktadır. Bu çalışma, araştırma, keşif ve eğitim amaçları için çok amaçlı bir robot tasarlama ve geliştirme üzerine odaklanmaktadır. Araştırmanın ana amacı, uzaktan kumandalı ve IoT teknolojisine sahip bir Rover robot platformu tasarlamaktır. Robotun farklı yeteneklerini test etmek için çeşitli senaryolar oluşturulmuş ve robotun performansı gözlemlenmiştir. Elde edilen veriler hem nitel hem de nicel yöntemlerle analiz edilmiştir. Geliştirilen Rover robotu hem RC hem de IoT kontrolleriyle başarıyla yönetilebilmektedir. Ayrıca, robotun IoT yönü için bir web sunucusu geliştirilmiştir ve robotun hem kol hem de kafa kamerası görüntüleri IoT olarak iletilmektedir. Robotun modüler tasarımı, farklı görevler için uygun olmasını sağlamakta ve eğitim amaçlı kullanıma uygun hale getirmektedir. Bu araştırmanın sonuçları, çok amaçlı rover robotlarının farklı alanlarda kullanım potansiyeline sahip olduğunu ve eğitimde de etkili bir araç olabileceğini göstermektedir.

1. INTRODUCTION

In the robotics industry, multi-purpose designs are preferred over single-purpose robots for specific emergency tasks to achieve higher efficiency/cost ratios in future robots. A robot must be multifunctional to address today's challenges, to be cost-effective, and to increase an organization's productivity [1]. Many traditional robots are designed for a specific purpose or usage area. Two different types of robots may be required for two different types of tasks [2]. This entails complexity in coordinating different robots for different tasks, as well as cost. Therefore, designing a multi-purpose robot that can perform multiple tasks on a single platform would be more cost-effective [3, 4]. Multi-purpose robots can perform multiple tasks simultaneously, thus saving both cost and time. Our research indicates that emergency robots are frequently encountered in the Robotics Industry, but upon detailed examination, most of them are specifically designed for a particular purpose, and due to the challenges in their usage, they are often deployed too late in emergency situations [5]. A point emphasized in speeches at the United Nations Conference is that robotic technology will play a critical role in emergency response, rescue, and emergency preparedness in the future [6].

Multi-purpose IoT rover robots have garnered significant attention in recent research. These robots are designed for various applications such as exploration, environmental monitoring, and educational purposes. The integration of IoT technology allows these rovers to collect and transmit data efficiently, enhancing their capabilities. In the realm of planetary exploration, researchers have focused on improving vision systems for planetary rovers to enhance their exploration capabilities [7]. Some studies focus on intelligent physical robots in healthcare. While the primary focus is on healthcare applications, the systematic literature review conducted in this research offers valuable insights into the broader use of robots, including multi-purpose IoT rover robots [8]. Additionally, the development of autonomous navigation systems using advanced algorithms has enabled rovers to navigate challenging terrains effectively [9]. Similarly, introduced a new potential field method for rough terrain path planning using genetic algorithms for a 6-wheel rover, demonstrating advancements in motion planning for wheeled mobile robots [10]. Moreover, the utilization of IoT technology has led to the creation of low-cost environmental monitoring mini rovers equipped with sensors for data collection and surveillance in confined spaces [11]. These compact rovers offer a cost-effective solution for monitoring various environments. In the context of multi-robot systems, the deployment of multiple robots operating as a team has shown significant benefits over single large rovers, including increased fault tolerance and parallel exploration capabilities [12]. This approach enhances the overall efficiency and robustness of exploration missions.

Educational robotics has emerged as a promising field with the potential to enhance teaching and learning processes. Research has shown that robots can improve engagement and elicit novel social behaviors, particularly in individuals with autism [13]. The development of open-source educational robots like the Mona robot has provided affordable platforms for teaching and research [14]. These robots offer opportunities to design pedagogically sound curricula and adequately train teachers to effectively incorporate educational robotics in K-12 settings [15]. Furthermore, the use of social robots as educational tools shows promise in supporting second language learning through interaction and repeated practice. Studies emphasize the importance of integrating educational robotics into teacher education to enhance pedagogical methods and improve learning outcomes [16]. Additionally, the design of educational robotics kits, such as those simulating sustainable cities, demonstrates the potential for hands-on, experiential learning in primary education [17]. Chronis & Varlamis, presented an open source and open design robot that can be used for educational purposes at all levels of the educational system, supporting many different activities and teaching scenarios [18]. Darmawansah et al. focused on trends and research foci of robotics-based STEM education, shedding light on the evolving role of robotics in educational settings [19]. Yu & Wang, 2022 provided a review of dexterous manipulation techniques for multi-fingered robotic hands, emphasizing advancements in reinforcement learning methodologies for robotic manipulation tasks [20]. Lastly, Wang et al. discussed distributed reinforcement learning for robot teams, highlighting the potential applications of multi-robot systems in various fields such as automated manufacturing and disaster relief [21]. Overall, the literature review highlights the diverse applications and technological advancements in multi-purpose IoT rover robots, showcasing their potential in various fields ranging from planetary exploration to environmental monitoring and educational initiatives.

The main objective of the study is to design a highly useful robot that can be used in many emergency situations. The developed robot has its web interface-based control, the platform also incorporates a radio control (RC) functionality. It has mobility capabilities in challenging terrain conditions and is equipped with IoT features, sensors, and cameras. The camera and sensor data are transmitted via IOT. It is partially autonomous and can be directed to a desired location remotely using GPS navigation. It can easily grasp and carry objects thanks to its arm. It can determine the distance of objects using the angle between two cameras and it can detect depth with an ultrasonic sensor. Besides, it can observe the surroundings by extending its arm into places that the robot cannot enter with the camera on the arm.

The developed robot offers a cost-effective solution while performing safe destruction tasks with explosion risk. The robot’s arm is used to carry suspicious objects and remove danger from the environment. It can autonomously extinguish fires with its liquid tank and pump in partial fire-fighting tasks. It can be used in tasks such as detecting gas leaks or toxic chemicals in hazardous areas where humans are present. Moreover, it has the capability to spray disinfectant in scenarios with infection risks such as COVID-19. Its ability to be used in challenging terrain conditions provides a significant advantage in disaster areas for rescue operations.

2. MATERIAL AND METHOD

In this paper, a Rover robot platform has been designed with remote control, IoT technology. This section will discuss the methods used in the development stage. The development phase of the robot is analyzed in two parts: hardware and software. The hardware was further divided into mechanical and electronic design. In the mechanical design phase, we based our initial model on NASA's Perseverance Rover Robot, incorporating Ackermann steering and rocker-bogie suspension systems. We then customized and evolved this design to better suit our specific requirements. The mechanical design involves creating the robot's structural body and ensuring its mobility. Key mechanical components include the main carrier body made from 20x20 mm T-slot aluminum profiles and the suspension system made from 20 mm aluminum pipes. The electronic design integrates various components to achieve the desired functionality. We used a Raspberry Pi-4 as the central processing unit and an Arduino Mega control card to manage sensor data and motor controls. Sensors such as the HC-SR04 ultrasonic distance sensor, DHT21 temperature and humidity sensor, MQ-135 air quality sensor, and Ublox GY-GPSV1 NEO-8M GPS module are included for environmental monitoring and navigation. The robot's movement and interactions are powered by servo motors. The software phase focuses on developing the control system for the robot, which is managed via a web interface. The control system is responsible for processing data from the sensors, sending commands to the actuators, and ensuring the robot's operations are performed as intended. The web interface allows users to remotely control the robot, monitor sensor data in real-time, and program the robot for various tasks. Our robot aims to minimize human risk in emergency situations, particularly in search and rescue operations where accessibility is a significant challenge. By combining programmable and radio-controlled features, the robot can be rapidly deployed and operated in disaster scenarios, providing critical assistance and improving the efficiency of rescue efforts.

2.1. General Design of Robot

The development process of our robot began with the completion of the mechanical components. This involved constructing the main body and implementing the mobility systems. Once the mechanical assembly was finished, microcontrollers and sensors were integrated onto the structure. The final stage involved programming the robot and conducting tests to ensure it performed the intended functions effectively. The general diagram of the robot is depicted in Fig. 1, illustrating the arrangement and connections of the electronic components used.

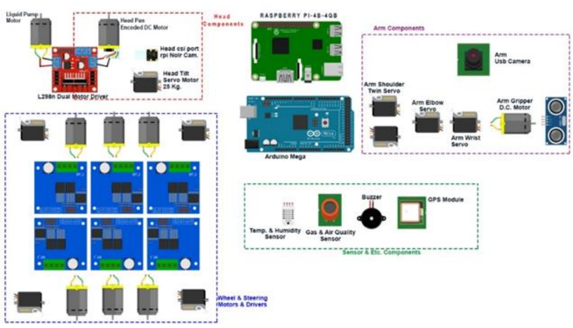

Figure 1. Diagram of the general electronic components of the robot.

Our robot utilizes both Ackermann steering and rocker-bogie suspension systems. The initial tests revealed that our suspension system was inadequate for off-road conditions. To address this, we redesigned the suspension using articulated axles, resulting in a two-axis suspension system. This improvement enhanced the robot's ability to navigate rough terrains. Additionally, the robot's body and wheel dimensions were enlarged, and we equipped it with more powerful motors. Specifically, we used 18-kilo torque motors with 110 RPM to boost its performance. The robot's control system allows for remote operation via the Flask Web interface, providing users with a user-friendly platform to manage and control the robot's movements and functions.

2.2. Body and Mechanical Design

The initial step in our study involved selecting components that are both cost-effective and high-performance. The main carrier body of the robot is constructed from 20x20 mm T-slot 6-channel aluminum sigma profile, providing a robust and flexible framework as shown in Fig. 4. The bogie suspension and articulated axle system, crucial for the robot's mobility, are made from 20mm aluminum pipe, as depicted in Fig. 3. To ensure precision and reliability, the connection and engine assembly parts of the robot were designed and manufactured using a 3D printer with Autodesk Fusion 360 software. This process is illustrated in Fig. 2, where the prepared parts are shown being printed and successfully tested.

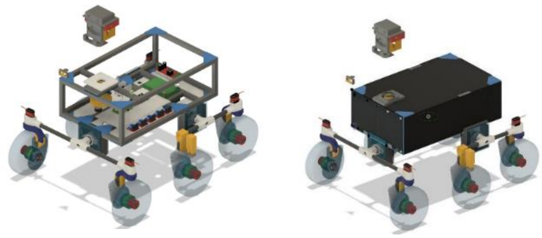

Figure 2. The Design of the Robot's Body Frame is shown in these images taken from the Fusion 360 Engineering Design Application.

Rocker-Bogie Suspension has been chosen for the robot. The Bogie system was used on NASA's Mars rover Sojourner and has been the preferred suspension system ever since. This system has been used on several missions, including the 2003 Mars Exploration Rovers Spirit and Opportunity, the 2012 Mars Science Laboratory (MSL) rover Curiosity, and the Mars 2020 rover Perseverance.

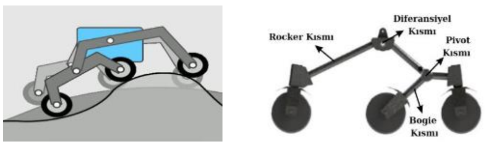

Figure 3. Rocker-Bogie suspension system

Figure 4. The body frame of the robot

Our robot's arm design features five movable joints across three axes, optimized for interaction with the environment. The visuals of the Robot Arm are shown in Fig. 5. The horizontal deviation axis is powered by a DC motor with an encoder, providing 360-degree rotation capacity. We used dual 25 kg-cm servo motors in the shoulder joint to meet the high torque requirements. The main structural element for the arm is a 20mm sigma profile. Cameras placed on the head and arm facilitate depth perception for object interaction.

Figure 5. Images of the Designed Robot Arm. These images show the D.O.F. structure of the robot arm, the way it grips objects, the design structure of the arm, motors, camera and distance sensor.

2.2.1. Motion motors, ackermann steering geometry and wheel motors

The robot utilizes Ackermann Steering Geometry as its steering algorithm, enabling the calculation of the turning radius based on the geometry of the steering mechanism. This system is implemented through a function that calculates the angles of the steering servos and the speeds of the wheel motors simultaneously, executed on the Arduino Mega microcontroller.

In our design, we opted to increase the driving speed using 110 RPM glass lifting motors paired with larger wheels. The choice of glass lifting motors is driven by their cost-effectiveness and their ability to deliver adequate power in terms of both torque and rotation speed. For more demanding tasks, we selected high-torque glass lifting motors with worm gear reducers. These motors provide a rotational speed of 110 RPM and a torque of 18 kg.cm (1.7658 N.m), offering a balance of speed and power suitable for a variety of terrains.

The wheels, which are 25.4 cm (10 inches) in diameter, enhance the robot's ability to traverse different surfaces. Using the provided Eq. (1), the force exerted per wheel is calculated to be 27.76 N.

$$F_{onewheel} = \frac{Torque}{R_{wheel}} = \frac{36kg.cm}{12.7cm} = 2.83kgf \quad (1)$$

2.3. Electronic Design, Microcontroller and Sensor Components

IoT (Internet of Things) refers to the ability of everyday objects to communicate and exchange data with each other via the internet. This technology enables various smart devices (e.g., thermostats, lights, cameras) to connect to the internet, share data, and be controlled over a network [22]. MQTT (Message Queuing Telemetry Transport) is a lightweight and low-resource-consuming message-based protocol used for machine-to-machine communication. It is especially preferred in the IoT ecosystem. Almost all IoT cloud platforms support the MQTT protocol due to its practical use and resource friendliness [23]. The reason for using IoT in our study is to obtain sensor data for detecting the robot's surroundings and to facilitate the transmission of user-designed program codes for remote control, along with manual control commands. Additionally, IoT is utilized for transmitting images captured by the robot's two cameras.

This section describes the electronic modules used in the robot, their features, and the tasks that these modules undertake in the robot. Raspberry Pi 4 and Arduino Mega 2560 were utilized in the study. Raspberry Pi is a single-board computer that includes basic components of a computer such as processor, RAM memory, input/output units, all on a single card. These computers can be used as desktop computers in robotic projects, smart home systems, embedded systems due to its compact design. The Arduino Mega 2560 was used for tasks such as the operation of sensors and motors and the transmission of data received from the controller to the Raspberry Pi. Moreover, the HC-SR04 ultrasonic sensor was used for the robot to avoid obstacles. The Ublox GYGPSV1 NEO-8M GPS module is used to determine the robot's position in the terrain and also to enable autonomous progress between locations. This module can communicate with both GPS and GNSS satellites and has a location accuracy of 2-2.5 meters. It also supports 72-channel satellite communication. The DHT21 digital temperature and humidity sensor was used to measure the temperature and humidity of the physical environment. The MQ-135 air quality sensor is used to detect gases such as NH3, NOx, alcohol, benzene, smoke, and CO2 in the environment. The measurement accuracy can be adjusted with a potentiometer.

2.4. Software Components for Robot

2.4.1. Software to send sensor data with wifi module

The software running on Raspberry Pi is developed in Python. This software creates scripts from the movement and arm position commands coming from the remote control computer via MQTT messages using the Paho-MQTT library. These created scripts are transmitted to Arduino Mega in JSON format via the I2C protocol and the robot's movements are controlled in a coordinated and precise manner. In addition, data from sensors and cameras are transferred to the control computer via the MQTT protocol. This configuration allows Raspberry Pi to transmit sensor and image data to the control computer in real time.

The software on Arduino Mega performs basic microcontroller functions and reads data from sensors via serial, analog and digital ports, transmits and receives data from Rasberry Pi via I2C in JSON format, controls the motors and in addition, since our robot can also be controlled with RC, it manages the robot's movements and modes according to the RC-Control signals coming via sBUS with the RC receiver. In addition, the Ackermann Steering Geometry Algorithm is used for the Steering system and the data is converted in the range of 0-180 degrees according to the angle of the joystick.

2.4.2. Control computer flash web server software

A Python Flask Web Server based software has been developed for control. Separate web pages are designed for sensor data collection, control, monitoring, and programming functions in this platform. The home page lists the block coding instruction sets previously saved in the SQLite3 database and these instructions can be selected and loaded into the robot. The selected instruction sets are transferred to the Arduino Mega via Raspberry Pi and executed.

3. RESULTS

Our robot is controlled in two different ways considering various usage scenarios. These are Radio Controlled (RC) programmable with Python Flask Web server with IoT method.

In this study, RC control method is chosen in real-time image acquisition scenarios that require rapid response. Control is provided at a range of approximately 1 km using a RadioLink AT 10 remote control and a 2.4 GHz RadioLink R12DS receiver. The signals from the controller are monitored by sending an interrupt request to the Arduino Mega microcontroller. The Raspberry Pi processes the images with the Python OpenCV library and transmits them via a 5.8 GHz FPV transmitter. This ensures effective image communication.

IoT and MQTT are used for the robot to perform autonomous or manual tasks remotely. Special pages are designed for control and monitoring on Flask Web Server. Data communication is performed using the Python Flask web server and the Paho-MQTT library. Schematic representation of IoT control using Wi-Fi Signals is shown in Fig. 6.

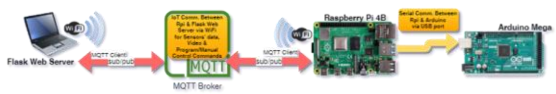

Figure 6. Schematic representation of IoT control using Wi-Fi Signals.

The communication method between the Python Flask Web Server on the Control Computer and the RPi and Arduino Mega on the robot is shown. Thanks to the suspension system of our robot, its mobility skills in off-road conditions have reached the desired level. The robot can be controlled manually in real time and with RC controller. Communication range is at the intended level. It is seen that the robot gave the desired results in IoT control tests from the website. It is also observed that the MQTT communication protocol works efficiently in terms of stability and speed. The robot can be effectively utilized in various scenarios. AI models in our robot will be of great benefit in emergency operations as they can be used for different purposes in many different tasks.

The robot arm can lift objects weighing approximately 1 kg as a result of calculating joint angles with a moment-reducing algorithm. With the special 3D joint apparatus designed, double servo motors were added to the joints to increase the force. Moreover, it can perform functions such as agricultural irrigation, autonomous spraying, and disinfectant spraying with a multi-purpose liquid tank pump.

The developed robot is compared with FOSSBot [18] in terms of mobility, sensor capacity, processing power, and manipulation capabilities as shown in Table 1. Our robot features Ackermann steering geometry and a rocker-bogie suspension system, providing high mobility and stability in challenging terrain conditions. The five-jointed robotic arm, with a 360-degree rotating axis and high-torque servo motors, allows significant interaction with the environment. Additionally, it is equipped with various environmental sensors and a dual-camera system. With Raspberry Pi 4 and Arduino Mega 2560 processors, the robot has high processing power and can be remotely controlled using Python and MQTT protocols. The robot also includes artificial intelligence and object detection capabilities, making it suitable for complex and challenging tasks such as search and rescue, environmental monitoring, and exploration. In contrast, FOSSBot [18] is a simpler platform designed for movement on flat surfaces, lacking a suspension system and robotic arm. It uses basic sensors and does not have a dual-camera system. FOSSBot is primarily intended for educational and research purposes, suitable for simple projects and basic robotic applications but limited in performance for complex and challenging tasks.

Table1. Developed Robot and FOSSBot Comparison Table

Criteria	Developed Robot	FOSSBot [18]
Mobility and Suspension	Ackermann steering geometry and rocker-bogie suspension system	Four-wheeled simple mobile platform, no suspension
Robotic Arm and Manipulation	Five-jointed robotic arm, 360-degree rotating axis	No robotic arm
Sensors and Sensing	HC-SR04 ultrasonic sensor, DHT21 temperature and humidity sensor, MQ-135 air quality sensor, Ublox GYGPSV1 NEO-8M GPS module, dual cameras	Basic sensors (ultrasonic or IR sensors), no dual cameras
Processing Power and Control Systems	Raspberry Pi 4, Arduino Mega 2560, and MQTT	Raspberry Pi or similar single-board computer
Task and Application Areas	Search and rescue, environmental monitoring, exploration, remote control	Educational and research purposes, simple projects

4. DISCUSSION AND CONCLUSION

In this study, an emergency response robot has been developed that allows people to assess the area, make detections, and perform the necessary interventions before entering dangerous environments. The developed rover robot can be successfully controlled both through RC and IoT controls. Furthermore, an IoT-focused web server has been established to cater to the IoT functionalities of the robot, facilitating the transmission of both arm and head camera imagery via both IoT and FPV channels. The robot's modular design ensures suitability for various tasks and makes it suitable also for educational purposes. The robot exhibits the potential for international utilization across diverse tasks, facilitated by its open software architecture for further development and the ability to integrate additional models onto the Raspberry Pi platform. The developed robot can be used in a variety of industrial applications like hazardous material handling and inspection. The robot can be used to safely assess and interact with dangerous environments, reducing human risk. Furthermore, the robot's ability to navigate rough terrains and obstacles makes it ideal for search and rescue operations. The developed robot can also be used as an excellent teaching tool for various STEM (Science, Technology, Engineering, and Mathematics) disciplines. Its open software architecture allows students and educators to experiment with programming, sensor integration, and robotics principles. By working with a real-world application, students gain hands-on experience in developing and controlling robotic systems, enhancing their understanding of both hardware and software components. Additionally, the robot's modularity allows for the inclusion of various educational modules, such as AI, computer vision, and IoT, offering a comprehensive learning platform that evolves with the curriculum. In future work, we are planning to expand the AI capabilities of the robot by using NVIDIA Jetson instead of Raspberry Pi. In this way, computer vision tasks will be carried out faster. In addition, we are planning to use a stereo robot camera for depth perception and an advanced LIDAR sensor for three-dimensional mapping of the environment. This expansion will not only enhance the robot's performance in terms of speed and accuracy but also open up new avenues for its application in more complex industrial tasks and advanced educational projects. The integration of more sophisticated AI and sensory systems will further solidify the robot's role as a versatile and practical tool in both industry and education.

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